AFRL-SR-BL-TR-98-

0476

REPORT DOCUMENTATION

-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Final 30 Sep 95 to 29 Nov 97

4. TITLE AND SUBTITLE
Spectral Metholds for High-Speed Optical Transmultiplexing and Coding

5. FUNDING NUMBERS
61103D
3484/FS

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
110 Duncan Ave RMB115
Bolling AFB DC 20332-8050

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-95-1-0533

11. SUPPLEMENTARY NOTES

19980615 038

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVAL FOR PUBLIC RELEASED: DISTRIBUTION UNLIMITED

13. ABSTRACT (Maximum 200 words)

This program is demonstrated all-optical methods for generation, processing, and transmultiplexing (data format conversion) of ultrafast lightwave signals. This work is based on a generalized space-time processing concept, where ultrafast time-domain signals are converted into the spatial domain, where they can be processed using parallel optical and smart pixel optoelectronic techniques, and then subsquently reconverted back into the ultrafast time domain. The program investigated GaAs/GaAlAs photorefractive quantum wells as a dynamic holographic medium for femtosecond pulse processing in spectral holograhy systems. Several optical error control code techniques and optical codes have been investigated over the last year, most based on optical spectral encoding technique ("spectal-null codes") improved bandwidth utilization and drastically reduced dispersion sensitivity can be achieved by encoding individual bits shaped as specific orthogonal waveforms. The results from this work, show that particular orthogonally coded waveforms can indeed be multiplexed "on top of each other" both in time and frequency and still remain orthogonal at the receiver end. We also show that dispersion, linear and nonlinear chirps do not affect the orthogonality properties of these waveforms.

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

DTIC QUALITY INSPECTED 3

Final report:

Spectral Methods for High-Speed Optical Transmultiplexing and Coding
F49620-95-1-0533

Dept. of Defense Focused Research Initiative on
Photonics for Data Fusion Networks

June 2, 1998

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I. Pulse shaping, pulse processing, and transmultiplexing

A key goal of our program is demonstration of all-optical methods for generation, processing, and transmultiplexing (data format conversion) of ultrafast lightwave signals. Our work is based on a generalized space-time processing concept, where ultrafast time-domain signals are converted into the spatial domain, where they can be processed using parallel optical and smart pixel optoelectronic techniques, and then subsequently reconverted back into the ultrafast time domain. Our results include the following:

- We have performed experiments using second harmonic generation (SHG) crystals within a femtosecond pulse shaping apparatus for femtosecond time-to-space conversion. Compared to our previous experiments utilizing dynamic semiconductor photorefractive thin films for time-to-space conversion, second harmonic crystals have a very fast response time which can enable Gigaframe/sec operation needed for high-speed communications and networking. This concept involving SHG was first demonstrated by Fainman *et al* (UCSD), who obtained a 0.1% time-to-space conversion efficiency at 100 MHz repetition rate using >100 mW average power from a modelocked Ti:Sapphire laser. We have recently performed similar experiments using a 6 mm long noncritically phase matched potassium niobate ($KNbO_3$) crystal resulting in greatly improved efficiency (exceeding 50%) at comparable power levels. This constitutes greater than 500 times improvement in efficiency for this scheme. We have also analyzed the factors governing the efficiency in time-to-space conversion via SHG and found that the key parameters are a large nonlinear coefficient and the ability to use noncritical phase matching which eliminates spatial walkoff to allow for long interaction length. The importance of this work is that with the efficiency achieved, it now becomes feasible to utilize this approach for cascaded time-space systems at very high speeds.

- We have obtained preliminary results with a modified pulse shaping geometry suitable for high-speed space-to-time conversion in cascaded time-space processing systems. In our previously established femtosecond pulse shaping technology, the output waveforms correspond to the Fourier transform of the spatial masking pattern. This is not suitable for the current application, where we desire that each bit in the output pulse sequence correspond directly to a single modulator element in a smart pixel array. Emplit *et al* in France previously demonstrated a modified pulse shaping geometry with the desired direct space-to-time conversion characteristic for simple phase shaping of a 7 psec input pulse. We have performed experiments demonstrating the ability to generate a femtosecond pulse sequence, where each pulse in the sequence directly corresponds to a specific opening in an amplitude mask. The optical setup is constructed in such a way that we should soon be able to directly insert an optoelectronic modulator array directly into the experiments for very high speed ultrafast packet generation.

- We initiated exploration of smart pixel device arrays for optical pulse shaping and processing systems. The particular smart pixel technology under consideration consists of arrays of gallium arsenide multiple quantum well (GaAs MQW) optical detectors/modulators, or SEEDs, bonded onto the surface of silicon CMOS (Si-CMOS) electronic chips. In collaboration with Prof. Kevin Kornegay at Purdue, we designed our first Ultrafast Optical Processing (UOP) chip during fall 1995 using 0.8μm CMOS technology. Chips were subsequently fabricated by Bell Laboratories under the auspices of the ARPA Consortium for Optical and Optoelectronic Technologies for Computing (CO-OP) program. We expect soon to incorporate this chip into our space-to-time converter described above. We have also designed a second UOP chip with an expanded set of functionalities using 0.5 μm CMOS technology, with delivery expected summer '98. Functionalities should include electronically programmable pulse shaping, time-slot interchange, optical header recognition, and ultrafast

digital optical logic operations, including XOR gating to implement a stream cipher for encryption.

- Stimulated by the high conversion efficiency obtained in our SHG time-to-space conversion experiments, we have also investigated direct SHG of femtosecond pulses using thick nonlinear crystals in the absence of a pulse shaper. Our results show that extremely high conversion efficiency into the blue can easily be obtained using moderate power femtosecond pulses from a modelocked Ti:sapphire laser and a thick (3 mm) $KNbO_3$ nonlinear crystal. For example, 75% conversion efficiency is obtained using 200 mW input average power, and greater than 50% conversion is obtained for average powers of only 50 mW! Usually thick nonlinear crystals are avoided for femtosecond frequency doubling applications, since group velocity mismatch substantially broadens the output second harmonic pulse compared to the input. This is also true here, but with rapid advances in compact and efficient femtosecond laser technology, it may become possible to use efficient frequency doubling of femtosecond pulses as a practical source of blue photons for applications not requiring femtosecond pulse durations. Furthermore, our work points out novel phenomenology, including a focusing dependence quite different from that observed in continuous-wave SHG, which appears not to have previously been explored.

- In addition, we demonstrated for the first time that programmable femtosecond pulse shaping can be applied to manipulate broadband incoherent light in the 1.5 μm optical communications band and collaborated with the group of Prof. K.A. Nelson at M.I.T. to demonstrate two-dimensional pulse shaping in which an array of spatial beams, each corresponding to a different temporal waveform, is generated.

II. Photorefractive Semiconductor Devices

We have investigated GaAs/GaAlAs photorefractive quantum wells (PRQWs) as a dynamic holographic medium for femtosecond pulse processing in spectral holography systems. We first studied the spectral phase response of the PRQWs. Our data showed that the diffracted pulses had a flat phase over their bandwidth. This means that there are no significant spectral phase variations that would distort and degrade the output pulses from a pulse shaper or spectral holography apparatus. Based on this information, we proceeded to demonstrate pulse shaping and processing using PRQWs. In these experiments a pair of spatially patterned beams from a continuous-wave HeNe laser or diode laser are used to write the hologram in the PRQW, which is placed at the Fourier plane of a pulse shaping apparatus and read-out using a spectrally dispersed femtosecond pulses. Using this approach, we have demonstrated the following:

- In the case of a spatially uniform reference beam and one spatially patterned signal beam, we can obtain shaped femtosecond pulses, where the pulse shape is either a direct replica of the spatial pattern on the signal beam or its Fourier transform, depending on the imaging condition between the spatial mask in the signal beam and the PRQW. For example, by using a simple slit in the signal beam, an ultrafast temporal square pulse was generated.

- In the case where both reference and signal beams are spatially patterned, one can obtain an output temporal waveform determined by the correlation of reference and signal spatial patterns. For example, using slits in both signal and reference beams leads in the time domain to an ultrafast triangle pulse, since a triangle pulse is the autocorrelation of a flat-topped pulse.

- By adjusting the holographic recording conditions, one can reach a nonlinear recording regime with strong saturation properties. This can lead for example to strong clipping of the central peak and enhancement of the sidelobes of a sinc-function spectrum, corresponding to an ultrafast square pulse. In this example this yields an effective high-pass filter response,